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Pore-Scale Investigation of CO_2 Exsolution from Carbonated Water in Sedimentary Rocks

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Geologic sequestration of supercritical CO_2 in saline aquifers and depleted oil and gas fields will cause large volumes of brine to become saturated with dissolved CO_2 at concentrations of 50 g/L or more due to the high CO_2 solubility in brine at elevated pressure and temperature. While dissolution of CO_2 improves storage security by removing buoyancy forces, risks still exist if CO_2 saturated brine escapes from the reservoir as the solubility of CO_2 decreases with hydrostatic pressure. The CO_2, released from solution, would expand or even form a separate phase at shallower depths after being transported through caprocks or seals. Previous studies (Zuo et al., 2011) have shown that exsolution results in a separate CO_2 phase with very low mobility. We hypothesized that the low mobility resulted from the dispersed morphology of CO_2 bubbles. The objective of this study is to understand the dynamics of CO_2 exsolution and the effects on reservoir flows at a microscope scale.

In this study, a silicon-glass micromodel was fabricated based on images of a thin section of a Mount Simon sandstone from Illinois, USA. The micromodel mimics the complexity of pore structures existing in real porous media in two dimensions and has a minimum aperture of 3um. Carbon dioxide exsolution was created by slowly extracting fluids from the micromodel, which was initially saturated with carbonated water under reservoir conditions (9MPa and 45C). An optical microscope was used to monitor and record the entire process. Instantaneous nucleation was observed in the micromodel at a constant pressure drop rate of 1MPa/h, followed by a rapid process of bubble expansion and cluster growth. Carbon dioxide bubbles were highly dispersed and poorly interconnected, even when the gas saturation reached as high as 53%. Compared to a drainage process in the same micromodel, at the same gas saturation, exsolution resulted in a greater number of bubbles, but with a smaller average size. Forty to sixty percent of exsolved CO_2 formed and remained at locations that were not invaded during drainage due to narrow apertures thus high entry pressures. This part of gas exhibited little mobility during the course of depressurization and clogged water flow paths. Exsolved gas formed in other portions of the micromodel was mobile and driven by a pressure gradient to move downstream toward pore throats, along with water flow, part of which formed intermittent gas flow and eventually escaped from the micromodel. This in-situ morphology of trapped gas contributes to the phase mobility reductions in porous media.